Machinery Fault Diagnosis and Signal Processing
Prof. A. R. Mohanty
Department of Mechanical Engineering
Indian Institute of Technology, Kharagpur

Lecture - 33
Rotational Speed Measurements

In the last class, we discussed about vibration monitoring and then I focused my attention mostly on vibration monitoring by accelerometers. And then introduce you to how lasers could be used to measure from a distance without contacting the normal vibration like in the case of the vibration from the compressor shell off a refrigerator.

Or rotational measurements for example, using a rotational laser vibrometer wherein we focused 2 beams to measure the fluctuation in the speed which is nothing but the rotational velocities. And this fluctuation who is at a frequency which is at the defect frequency of the system, but perhaps another very, very important parameter in any rotating machines to measure is actually it is rotating speed.

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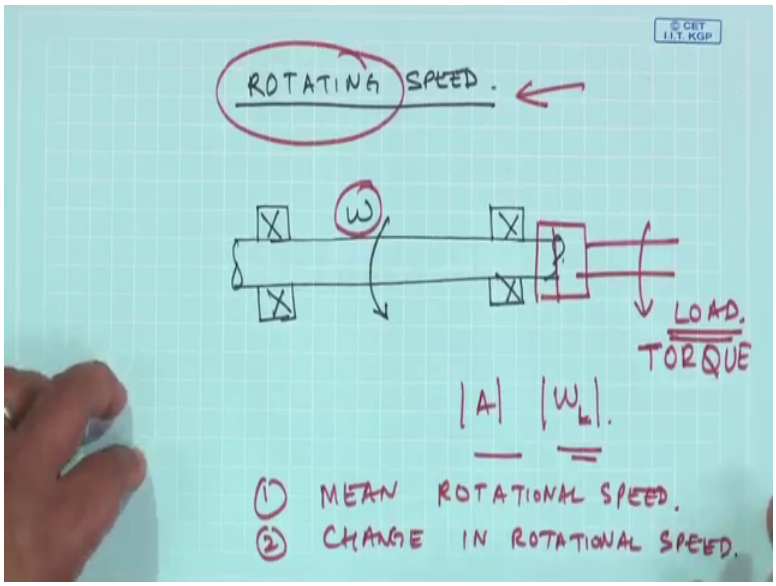

Because, philosophically is what happens when we design a machine I will come back to the example where essentially, we are dealing with machines where shafts are rotating and they are supported on bearings. Now, question is when such shafts are supported on bearings and they are coupled to some other systems which gives the power or the some load. Now, if this imagine this is designed to run at a constant speed omega, imagine if

this load torque for a moment varied. So, what is going to happen to the dynamics? Obviously, this load torque where I means either in terms of it is amplitude or in terms of it is omega.

So, this is going to change the rotational speed and also the vibrations. So, once there is a change in the rotational speed, it gives clue as to what is the cause behind this change that is one. So, one is the measuring the absolute rotational speed or mean rotational speed and next is change in the rotational speed. First, we will focus on mean rotational speed or the constant rotational speed.

Why this is important? Because, there is something called what is known as the forcing frequencies.

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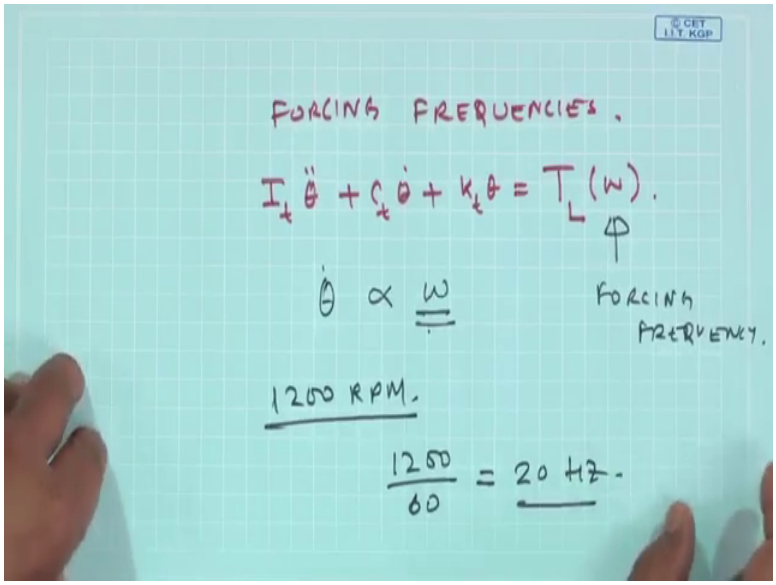

As you know, for any system you know if I if I write it in the rotational domain sum it theta dot plus Ct theta dot plus k t theta is equal to sum load torque TL which is a function of omega; obviously, this theta etcetera will respond at omega.

So, this is my forcing frequency and the response will be at the function of the forcing frequency. For example, a shaft is rotating at say 1200 RPM. So, what is a forcing frequency? Nothing but 1200 by 60 is 20 hertz this is my forcing frequency

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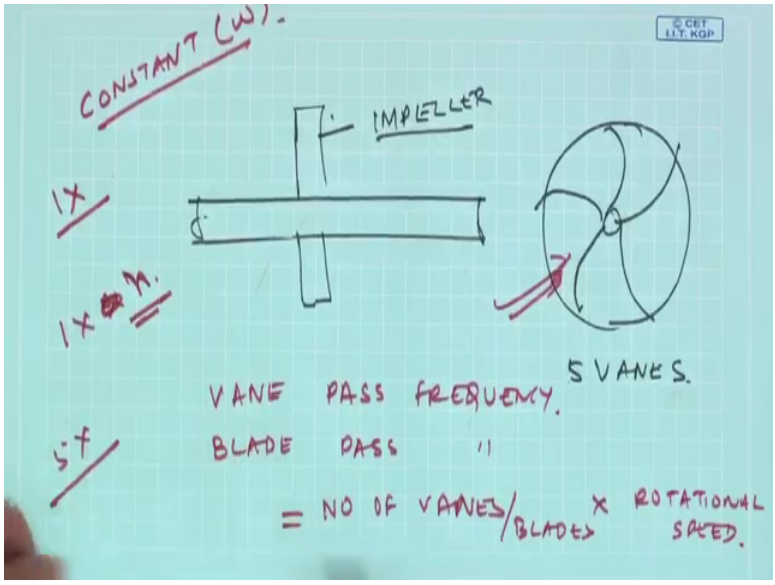

Now, imagine this shaft had a fan or an impeller may be I will draw the cross section here it had a impeller may be with may be 5 vanes. So, impeller so, imagine if there are some fluid which was going on to the system. So, you see every time the fluid in every rotation of the shaft the fluid is getting obstructed 5 times. So, the fluid is getting chopped if it is a blower if it had vanes the air would have been chopped. So, this is what is known has the vane pass frequency or the blade pass frequency. This is nothing but number of vanes or blades times the rotational speed.

Even, if the shaft was rotating at constant omega I will have rotational speed. Sometimes which relate in vibration monitoring as 1X and then there will be multiples if there are. So, 1X times 1X times n number of so, 5X if there are 5 vanes I will have a strong forcing frequency at 5X hertz and so on. So, this is how for a constant speed machines we need to measure the rotational speed. Now, what are the available transducers for rotational speed? So, you understand the significance of measuring rotational speed because, in a system when I am monitoring the vibrations you all know by now that if I have a machine.

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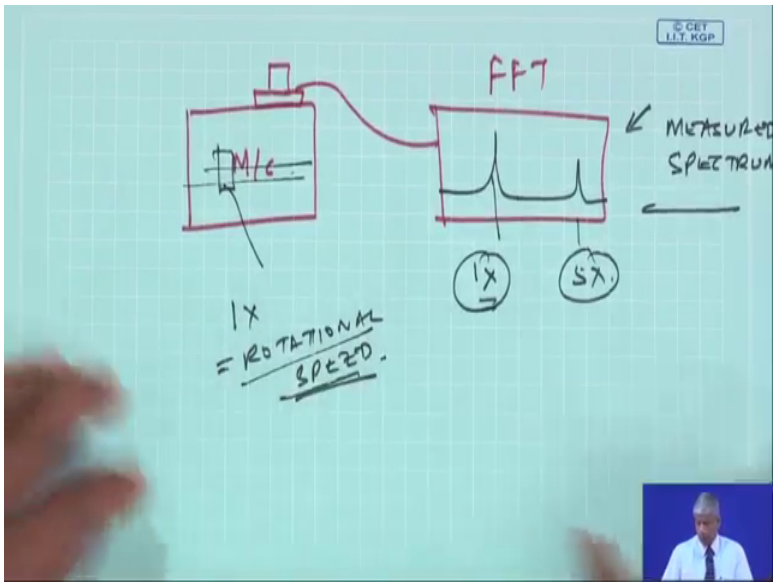

If I put a transducer to measure the vibration and if I do an FFT of it fast would it transform I will see certain peaks. So, this could be 1X or this could be 5X. So, you see this x is related to the rotational speed if there is a shaft here. So, when I am doing a fault diagnosis I will be looking for 1X and 5X frequencies in my measured spectrum measured spectrum.

So, for this frequencies to be known I need to know what the rational speed is? Even the mean rotational speeds. Now, the way to measure it very cheaply you know what we can do is you know if I have system like this.

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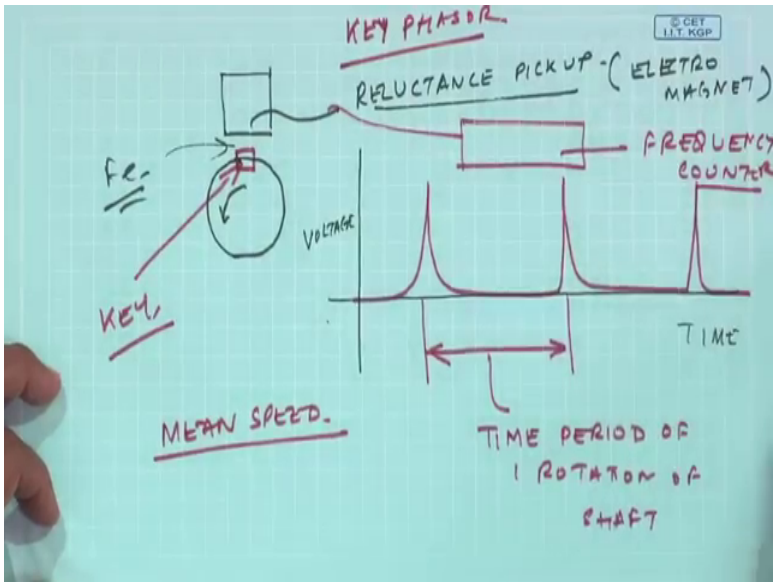

See, every shaft they have a key way if I put a key here and I put a pickup or reluctance type electromagnetic pickup. Of course, there is a casing in all that so, this is a reluctance pick up. What happens with the shaft is rotating? Each time the key comes below this reluctance pick up the voltage the gap is going to change.

So, there will be a change in the voltage. So, what is going to happen? If I look just from the in-time domain if I look at the voltage coming from this reluctance pickup, I would get peaks like this. And the interval between 2 consecutive peaks is nothing but the time period of rotation time period of 1 rotation of the shaft. So, what is this essentially? This is a very small electromagnet. Of course, this has to be iron this has to be which is influence by magnets or electromagnetic forces.

So, what happens if I measure such a strain and this is there is no power required. You can see how easily just by putting an electro magnet just close to a shaft in every time there is a protrusion in a shaft. Because, of the key way this is the key this red one is the key every rotation I am going to get a pulse.

And the distance between these 2 pulses and time period I can take it for a longer time and then measure these pulses over a given period of time and come up the mean speed mean speed. And this can be directly connected to a frequency counter Nowadays, it is nothing but a frequency counter. So, this is and these are very robust. So, in every industrial environment such frequency counter-based reluctance type pickups are used to

measure the mean rotational speed. But, we will see scenarios when there is a momentarily change in the load even within one rotation there is a speed change we will talk about that later on.

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So, this is in some of the trade names of the reluctance pickup one is what is known as a key phasor. There is a company who deal with this key phasors and they have named it. All are required, if there is an electro magnet here some of them also have capacitance probe. So, because you know if the gap changes capacitance should also change so, such capacitive transducers are also used.

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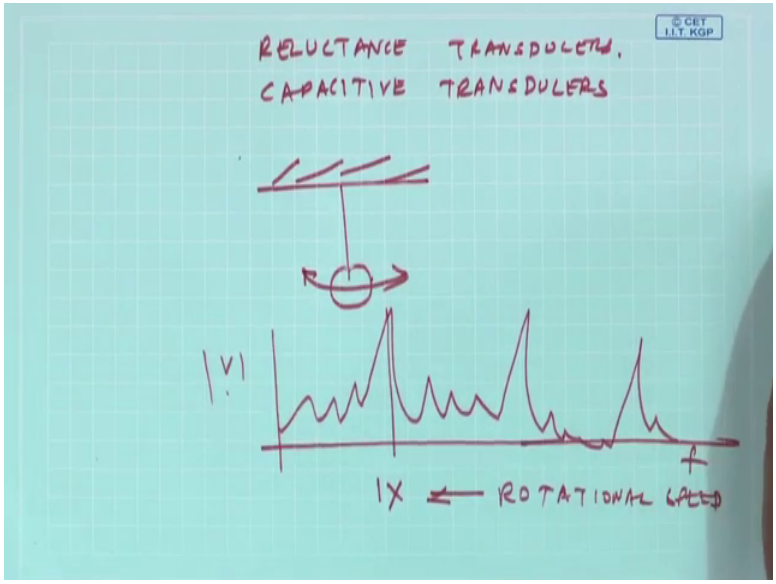

Reluctance type transducers, but; obviously, you know many scenarios I have seen you know when you go to the industry, the things are happening very slowly like the pendulum. We can measure the frequency just by measuring the time period counting the time period. I have been to plants where you know periodic tic-tic noise occurs so, sometimes you know this could be because of you know some phenomenon happening.

So, I just measured looking at my watch how much time it has taken between few ticks. So, we can find out the frequency of that event, but you know these are only good for very slow speed measurements you know. When we have high speed measurements because of these pickups also have their frequency limitations.

Sometimes, I also indirectly you will see when we measure vibrations the piezoelectric and accelerometry which you put if you mark measuring the vibrations spectrum something like this. May be even in 1X it will shoot up and that would be due to the rotational speed. Just by measuring the vibration you can find out the rotational speed.

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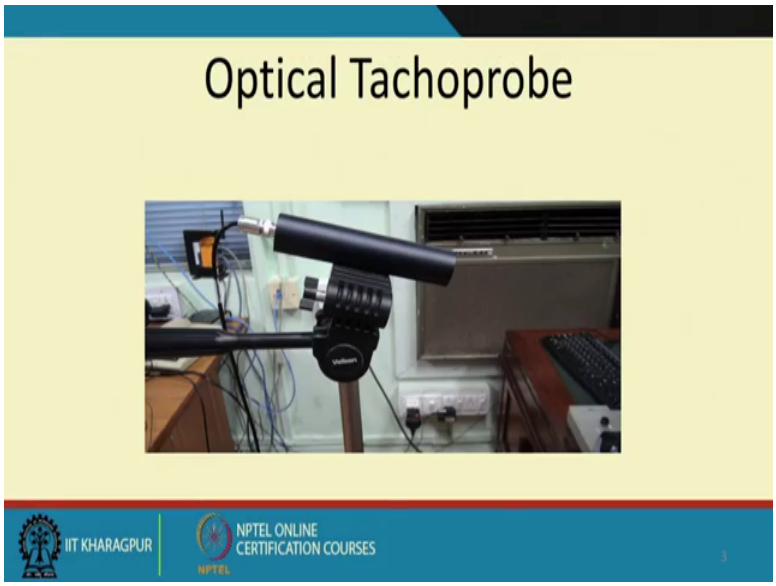

Of course, you know all these rotational speeds some are the contact type,.

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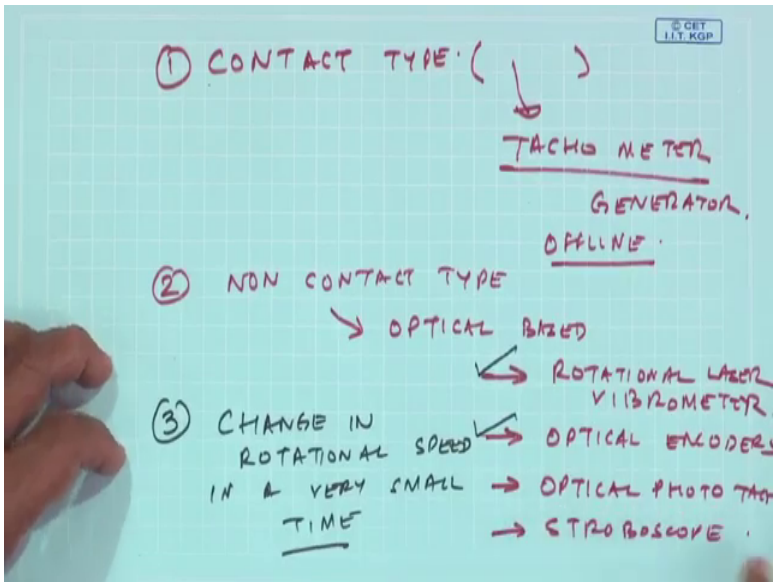

And this is this should be loading the system, but then contact type, you know measuring something or like a tacho meter or a tacho generator. For example, I have a very, very large turbine I could put the reluctant type pick up, but you know sometime momentarily offline one wants to measure the speed of motor electrical motor. The technician usually puts a tachometer where it is just offline once time measurements, but it is mostly this noncontact type speed measurements. The previous 2 which we talked about then we

have lot of this optical based measurements like we could have used the rotational laser vibrometer. But, they are very costly and rather, but then you can use the optical encoders. And of course, you know we have the optical photo tack or we also have what is also known as stroboscope.

So, depending on what kind of instruments we are going to measure or now what is the severity and frequency range and so on, but I have still not told you that how to measure the change in rotational speed momentarily change, change in rotational speed, in a very small time. What is known as the fluctuation in the rotational speed? I can use the rotational laser vibrometer, I can use optical encoders. And these sometimes could be used to find out the mean speeds using a non-contacting time noise. So, this is the view of an optical tach probe or photo tack what happens?

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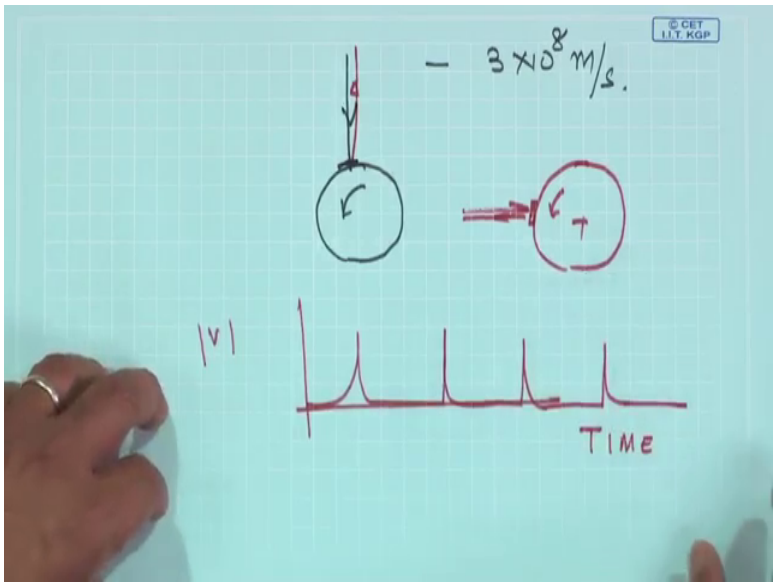

All we do if a shaft is rotating we shine a light. As you know the light speed is very, very high 3 into 10 power 8 meters per second.

So, almost instantaneously you will get a reflection back. And if I have on the shaft if I put reflective tape. So, immediately instead of a reluctance type pick up where we looked into the magnetic field. Here, it is just again I will get a voltage pulse, but this is due the optical effect. Some voltage again by measuring the time difference I can measure the speed at which this is rotating, but then there are scenarios.

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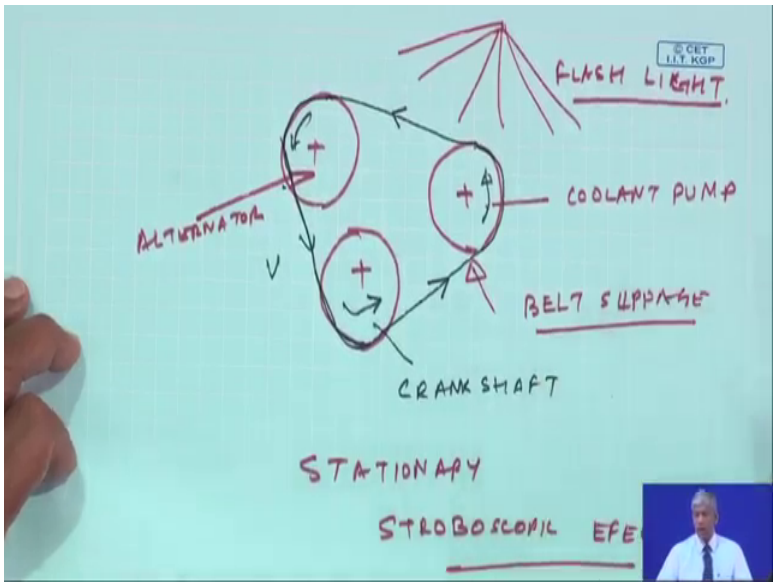

And of course, where had perhaps given this to you earlier also. In a system where in one setoff pulleys, pulleys are driven by a belt is my belt. A good example is the crankshaft alternator easy compressor of an automobile if everybody is rotating. An one is powarding may be this is the crankshaft. This is an alternator and this could be your you know may be your you know coolant pump. Of course, there will be a few like the easy compressor etcetera, etcetera, but just for the sake of discussion I am doing this.

Now, imagine all of them are must have the same linear speed. Because, this a belt which is doing round of course, and depending on the RPM and the diameter this omegas could be changing. Now, if there is a slippage of the belt and if I if I put a light here flash a light onto this entire thing, very flash if I flash the light onto this at a frequency related to what was the speed? And if they are all running at constant speed. They will if they flash light frequency matches to the frequency rotation of this. They would appear to me as stationary and this is the stroboscopic effect.

So, there is stroboscope wherein actually is nothing but a arrangement where we have a high flashing no there earlier they is to have a high intensity krypton lamp.

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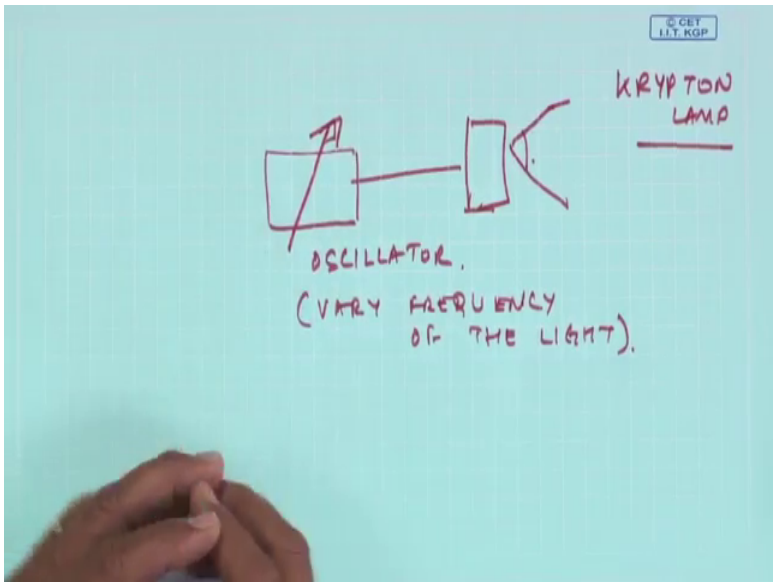

Of course, now a days we have the led lamps so, this is flashed onto surface where in I have an oscillator. Of course, it will have a power supply so on. So, I can vary the frequency of light vary frequency of the light. I do not know many of you would have gone to disclose you know if you if you have seen when a people dancing around and if you flash a light on to them they will appear to you to be static.

In fact, photographers use this technique to image a systems which are moving at very high speeds and you can get a stationary image. So, if it is flashed onto this light so, how does stroboscope other than measuring the speed of the system help us diagnose default? It is for the fact that, imagine if one of them was not running at a constant speed of the belt was slipping. Belt slippage so, then if I flashed the light what would happen? Is this belt would have been appeared to slide over the surface.

So, by stroboscopic arrangement I can find out the rotational speed of such systems and find out the slips in defective systems. But then, but another important thing is what is known as this optical encoder?

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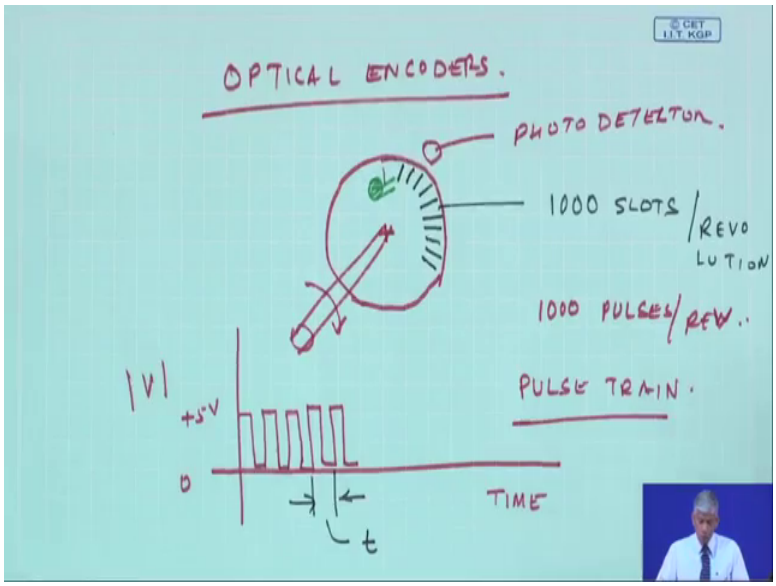

See, you see you are getting a feeling that without even monitoring vibrations just by carefully measuring the rotational speed of systems which are moving at a constant speed. If there is a fluctuation in speed, we can get some clue as to with condition of this machine. Right and if I talk about optical encoders see optical encoders are nothing but a disk which have slots on the perform on the periphery I am not drawing all these slots, but all around they are.

So, this could given as a 1000 slots per revolution; that means, and now if I have an arrangement where in I sign a light source at one end. And I have a detector photo detector at the other end. So, what happens in one rotation? You see in the case of the reluctance type pickup or the photo tack type pickup I got one pulse per revolution of the shaft. Here, what I am going to get is I will get pulsed stream of how many 1000 pulses per revolution.

So, this is still in time domain so, this is some voltage usually 5 volts sorry 0 to 5 volts. So, I need to have a light source and this of course, this optical photo tack is; obviously, connected to the shaft which is rotating. And then I will put a photo detector and this is housed. In fact, in some of the earlier slides I had you have seen the image of such optical encoder. And we will get this pulse of course, because it is 1000 pulses per revolution and even if the motor machine was running at very, very high speeds and even in few seconds you will get so many pulses. So, you are get basin basically getting a

pulse train. So, from this pulse train the average and each one of them is a time period. This is I am denoting purposefully by small t where 1000 such small t s would make up one time taken for one revolution or one rotation of the disk, but then there are signal processing algorithms or let me tell you what happens.

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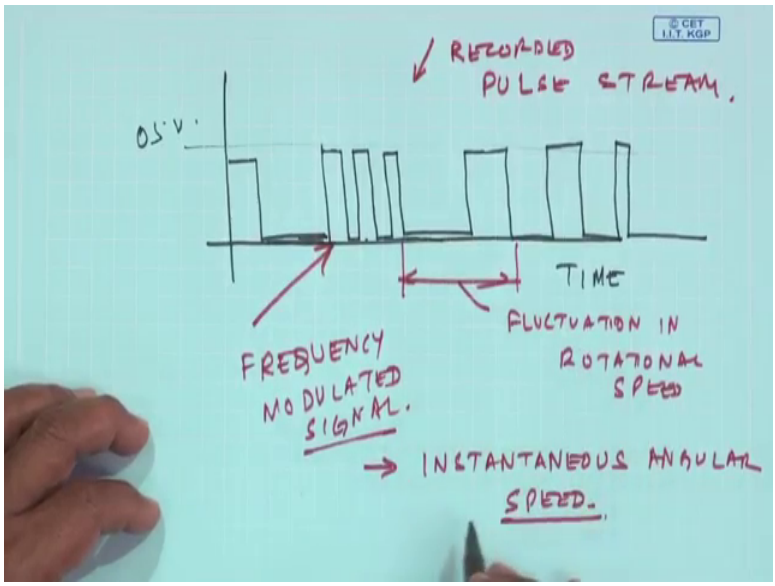

So, imagine if this pulse train and if I look at a very magnified view here it may. So, happen even in one duration the spacing would change the amplitudes are same. So, this becomes in other words frequency modulated signal and by analyzing this with an method called the Hilbert transform, which we have studied earlier. I can find out what is known as instantaneous angular speed of the shaft. Excuse me now, the question is why this time change?

So, there is a fluctuation in the rotational speed. So, today the state of the art is people use optical encoder or encoder basically if you think of this every machine be it a lathe machine, be it a noise you know electrical motor, people have optical encoders for the feedback circuit to measure the rotational speed. And to maintain the rotational speed through a control mechanism, but imagine if this rotational speed pulse stream was recorded pulse stream was recorded and we did an intuitive analysis of this. We could find out this instantaneous angular speed.

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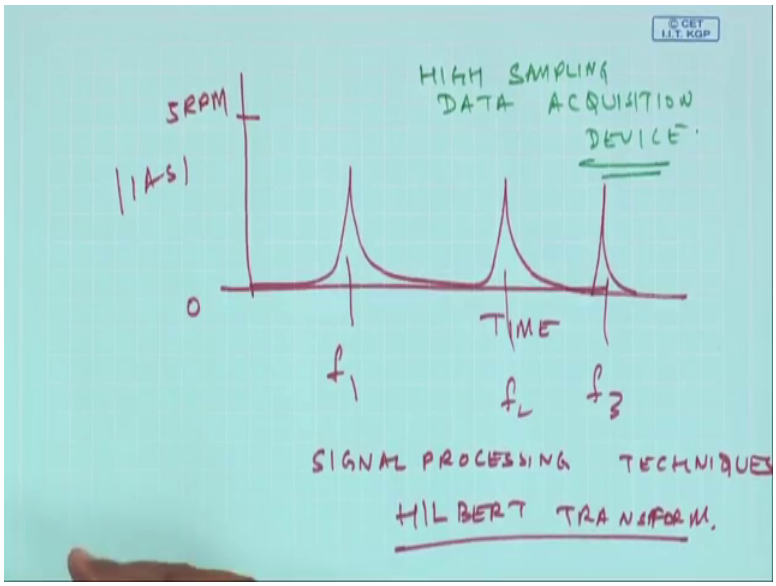

And later on, we will see these time virtues the IAS instantaneous angular speed you will see this variation could be very less even from 0 to 5 RPM. You will see may be in some frequencies these could be f1 f2 f3 this could be defect frequencies. And today this is the state of the art in CBM that just by measuring the instantaneous angular speed through very cheap rotary optically encoders. We can also find out the defect frequencies or as to what is wrong in this system and these could now be used with signal processing techniques like Hilbert transform, which we have discussed earlier and I had given you some examples also.

I can find out the defects in machines and only catch here is, I need to have a high sampling data acquisition device. So, such systems are in place and we can find out the rotational speeds. So, in summary we discussed about both the mean speed measurement transducer for rotational speed like the reluctance type pick up, the capacitive type pick, up the photo tack, stroboscope and of course, to find out of course, we can also use the rotational laser vibrometer.

But now, a day's trend has been to find out the fault frequencies because of the instantaneous angular speed. And that can be measured also by an optical encoder or even or rotational laser vibrometer and these techniques this are the you see without even using vibration, we can monitor the speed fluctuation and speed and then try to diagnose and find out the faults in machines. This is what the new technology is going to be so on.

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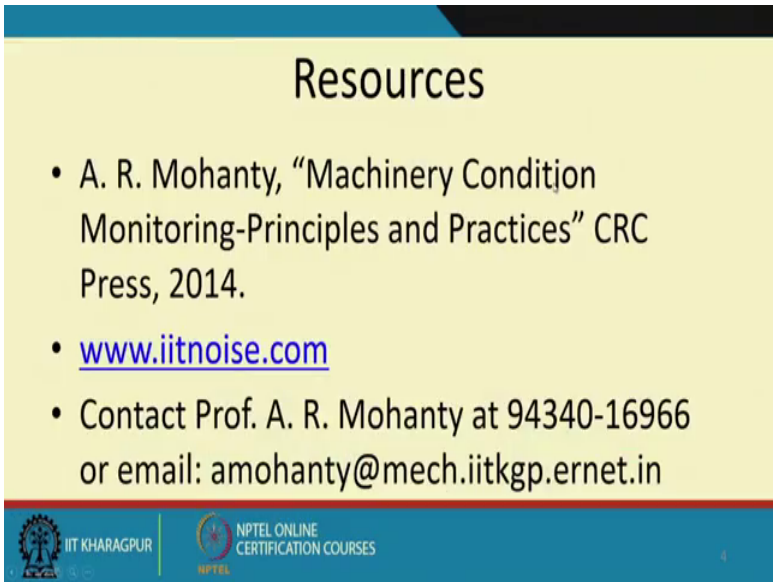

So, more of these you can find in my book.

Thank you.